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Analysis Of Changes In *Seismic Rate (Seismic Rate Change)* Based On Seismotektonic Spatial Distribution Of Bengkulu Area

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Abstract: Bengkulu Province has a high level of seismicity with significant earthquakes preceded by the phenomenon of decreased seismic activity (seismic quiescence) which can be seen through observing changes in seismic rate in an area based on the spatial distribution of z values. This study uses data from the USGS website for the period 1925-2021 to study seismic rates changes based on the spatial distribution of z values. In this study there are seven research focus zones, five major earthquake zones 1934 (7.0 SR), 1943 (7.0 SR), 2000 (7.0 SR), 2001 (7.0 SR), 2007 (7.7 SR), as well as two seismic activity zones with coordinates -5.6° to -4° south latitude and 101.6° to 103.4° east longitude and a seismic gap zone with coordinates –4.2° to -2.5° South latitude and 102.6° to 104.5° East longitude. The observation result show that before the earthquake occurred in the period 1925-2021, Before the earthquake, there had been a seismic quiescence phenomena. Four years before 2021, the seismic quiescence phenomena occurs in high seismic activity zones., while the seismic gap area occurs seven years before 2021. Overall, the seismic activity analysis result in Bengkulu province area shows an increase and decrease in seismic activity simultaneously in several different areas. This should be suspected of being the beginning of a significant earthquake in the future.

Keywords: Earthquake, seismic quiescence, seismic rate change, z-value

1. Introduction

Indonesia is the world's largest archipelagic country which is also a country that is very prone to natural disasters [1]. Western Indonesia has tectonic activity which is indicated by collisions between Indo-Australian Plate with the Eurasian Plate. In the eastern part it is shown by the collision activity of the Indo-Australian, Pacific and Eurasian plates [2].

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Bengkulu Province is one of the areas prone to earthquakes. This is because Bengkulu Province is close to the subduction zone which is the meeting point of the two world tectonic plates, namely the Indo-Australian Plate and the Eurasian Plate. These plates are active plates that move in opposite directions, where the movements of Indo-Australian Plate to the north while the Eurasian plate moves to the south and collides. This subduction zone is the main generator of tectonic earthquakes in Bengkulu Province [3].

Earthquake is a vibration or shock that occurs on the earth's surface as a result of a sudden release of energy beneath the surface. This is characterized by the breaking of rock layers in the earth's crust. Earthquakes occur due to the movement of rock layers on the earth's surface due to the release of energy in the earth's crust. This release of energy causes deformation of tectonic plates in the earth's crust [4]. Earthquakes occur when energy stored in the earth is released suddenly, usually in the form of stress on rock. This release of energy causes deformation of the tectonic plates in the earth's crust. This energy is propagated to the earth's surface by earthquake waves [5].

Earthquakes as destructive catastrophic phenomena can be classified into four types (1) volcanic earthquakes (volcanoes) which occur due to magma activity that can occur before the volcano erupts, (2)tectonic earthquakes that is caused by tectonic activity, namely the shift of tectonic plates that have varying strengths, (3) collapse earthquakes that is usually occur in limestone areas or in mining areas, and (4) artificial earthquakes, artificial earthquakes are vibrations on the earth caused by human activities such as dynamite, nuclear, or hammer explosions which is struck to the earth's surface for exploration activities [6].

Bengkulu Province is not only affected by the subduction zone but also by the source of tectonic earthquakes on the mainland, namely the Sumatran fault (the Semangko fault). This situation makes Bengkulu Province very vulnerable to disasters. Since 2000, there have been two large-scale tectonic earthquake events in 2000 and 2007 [7].

Through the analysis of the frequency-magnitude distribution, spatial variations of the a-value and b-value tectonic parameters of an area are obtained. A-values and b-values are seismotectonic parameters that can determine the level of seismicity of an area. According to seismologists, the spatial distribution of tectonic parameters, a low b-value reflects high local stress conditions of rock and conversely a high b-value spatial distribution reflects local stress conditions low rock. While the low a-value spatial distribution of tectonic parameters reflects a low level of seismic activity and conversely a high a-value spatial distribution reflects a high level of seismic activity [8]. Using the following linear equation, Gutenberg and Richter calculated the B value based on the connection between magnitude and frequency. [9]:

$$\text{Log N} = a - bM \quad (1)$$

When the magnitude of an earthquake is represented by M and its magnitude is represented by N, then a and b have constant values. Seismic mapping is used to categorize a region with other locations based on seismic characteristics. High seismic activity is represented by big a-values, whereas low seismic activity and return periods are indicated by low a-values [10].

To see the potential and prediction of significant earthquakes in the future, it is done by looking at the Z-value distribution [11]. Z-value is one of the statistical parameters used to analyze seismic rate changes. The technique used to describe changes in the seismic rate is the phenomenon of *seismic quiescence* by determining the Z-Standard Deviation [12]. The *z-value calculation is* done using

ZMAP ver 6.0 software. ZMAP is a MATLAB-based *Graphical User Interface (GUI)* software developed by Stefan Wiemer et al. since 1993 for seismicity analysis [13].

Seismicity is the distribution of earthquakes which is caused by various things, including sudden displacement of the earth's crust mass, volcanic activity and explosions caused by humans. Seismicity (seismic activity) can be used to define the geography of earthquakes, especially their magnitude or energy and their distribution above and below the earth's surface [14]. Seismicity is a measure to compare the seismic activity of an area with other areas. To determine the distribution of active earthquake zones or patterns of seismic activity based on the analysis of the magnitude-frequency relationship, it can be obtained by describing the distribution pattern of seismicity parameters which is related to a branch of science based on seismology and studies earthquakes and plate tectonics as well as the existence of faults in an area called Seismotectonic.

Seismotectonics has three parameters: a-value, b-value, and z-value. The degree of seismic activity in a region is described statistically by the a-value. The b-value is a statistical value used to represent the local stress state of rocks in a region, whereas the z-value is a statistical value used to monitor seismic quiescence occurrences [2].

The z-value method used to calculate the seismic rate changes by measures the difference in the seismicity level moving in the time window with the level of background seismicity using the deviation of Z-standard. The Z-method purpose to detect the possibility of low seismicity period anomalies before the occurrence of a big earthquake [13].

This method has been used previously by several experts terrestrial, such as Kei Katsumata (2011) who researched Precursory Seismic Quiescence Before the Mw=8.3 Tokachi-Oki, Japan, Earthquake on September 26, 2003 Revealed by a re-examined Earthquake Catalog. Results is the research found that before the Tokachi-oki event (2003) there was 5 two adjacent seismic quiescence anomalies. The anomaly appears in 1999 and lasted for 5 years before the Tokachi-oki event 2003 [11].

This study is based on Wela Yuliana's research from 2017 on There are five zones that have a seismic gap, the seismic quiescence phenomenon first year at the start of 2015 and three years at the start 2015 saw an increase in seismic activity. In general, distribution results spatial z-value in the West Sumatra region shows that at At the beginning of 2015 several areas of West Sumatra experienced reduction in seismic activity [2].

Calculating the z-value for the Bengkulu Province area will produce seismic rate changes. Through seismic rate changes analysis, it was found that the seismic quiescence phenomenon preceded significant earthquakes in Bengkulu Province. which can provide benefits for disaster mitigation and urban development planning.

2. Materials and Method

The National Earthquakes Information Center US Geology Survey (NEIC/USGS) website's earthquake catalog is used in this study, International Seismological Center and BMKG Padang Panjang with an observation period from 1925 to 2021. The z-value calculation is done using ZMAP ver 6.0 software. ZMAP is a software in the form of a Graphical User Interface (GUI) based on MATLAB [13]. Figure 1 is the flowchart of seismic rate changes.

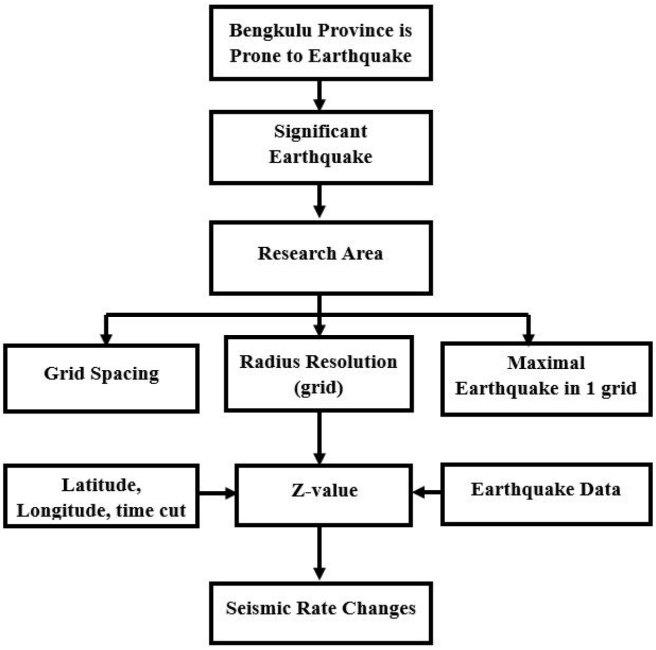


Figure 1. Seismic rate changes flowchart.

Convert each earthquake's magnitude into a magnitude body type (mb) before processing the data. The reason for this is that the data from the USGS website have a different kind of magnitude. Data should be converted before being entered into the ZMAP program. Furthermore, data declustering using the Reasenberg (1985) technique was done to remove the impacts of foreshocks and aftershocks. There are tools in Zmap that can show the spread of seismic activity on a map of the Bengkulu province.

To study variations in the seismic rate (seismic rate change), the geographic distribution of z-value is used. The first step in computing the z-value is to split each region into a grid of units of 0.1 x 0.1. Every 100 events, the number of occurrences in each grid is determined. Equation (2) is used to compute the Z-value [15]:

$$z(t) = \frac{(R_{bg} - R_w)}{\sqrt{\frac{S_{bg}}{n_{bg}} + \frac{S_w}{n_w}}} \tag{2}$$

R_{bg} is the average seismicity level throughout all data, excluding the chosen interval period. The chosen seismicity level is R_w. S_w is the chosen variation period. The total number of earthquake occurrences in the chosen data n_{bg} and n_w [15].

The number of chosen earthquakes at each ZMAP node may be used to determine the z-value. T is the length of time between T-start and T-end divided by Nt. Equation is used to calculate background level(3):

$$R_{bg} = \frac{1}{n_{bg}}\left(\sum_{i-1}^{N_1} n_i + \sum_{i=N_2+1}^{N_{\Delta t}} n_i\right) \qquad n_i = 1, \dots\dots, N_{\Delta t} \tag{3}$$

Where $n_i$is a large number of earthquake data points are calculated in the time window (ST), and n_{bg} in equation (2) has the same value as $N_1 + N_{\Delta t}$-N_2 $N_1 + N_{\Delta t}$-N_2 is the final time window before entering the long-term time window (LT), which has a width of t. Equation (4) may be used to calculate Seismic activity during the (LT) time window

$$R_w = \frac{1}{n_w} \sum_{i=N_1+1}^{N_2} n_i \qquad (4)$$

where n_w=$^{\Delta T}/_{\Delta t}$ then compare R_w to R_{bg} using equation (1), use the equation (5a) and (5b) to calculated the variation for S_{bg} and S_w .

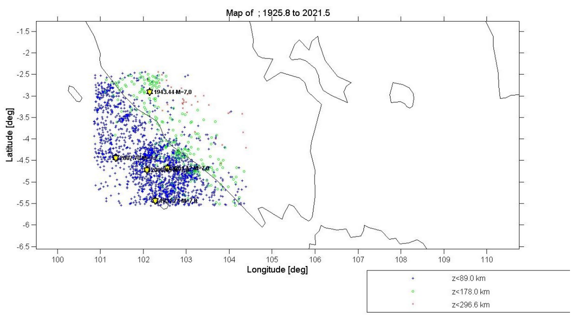
$$S_{bg} = \frac{1}{n_{bg}} \left\{ \sum_{i=1}^{N_1} \left(n_i + R_{bg}\right)^2 + \sum_{i=N_1+1}^{N_{\Delta t}} \left(n_i - R_{bg}\right)^2 \right\} \qquad (5a)$$

$$S_{w=\frac{1}{n_w}} \sum_{i=N_1+1}^{N_2} (n_i - R_w)^2 \qquad (5b)$$

The data of seismicity level is given by the positive z-value, which compares the mean seismicity at the interval we chose to the total seismicity level. A negative z-value also denotes the average growth throughout the chosen timeframe. The observed difference increases as the z-value increases [16].

3. Results and Discussion

The earthquake data used in this study were 2297 events from 1925 to 2021 which occurred in the Bengkulu Province at coordinates -5.6° to -4° South Latitude and 101.6° to 103.4° East Longitude. The magnitude used is M 3.0 SR with the type of body wave magnitude (mb). The depth of the earthquake used is limited to 300 km.



(a) (b)

Figure 2. Seismicity Regional (a) The map of Bengkulu Province Seismicity distribution. (b)Latitude and longitude 3D graph variations with respect to depth.

Figure 2 (a) As can be seen, Bengkulu Province had a high number of earthquakes between 1925 and 2021. Five distinct earthquakes with depths ranging from 7.0 M to 7.7 M were recorded. In Figure 2(a) the depth is identified in blue with a depth of D < 89.0 km which is grouped as shallow earthquakes, green color with a depth of D < 178.0 km which is classified as a moderate earthquake, and red color with a depth of D < 296.6 km which is grouped as an earthquake. Based on Figure 2(a), most earthquakes in Bengkulu Province are shallow earthquakes that occur in waters, while shallow and deep earthquakes occur on the coast to high areas. The number of earthquakes can be seen from the cumulative number curve in Figure 3. This cumulative maneuver curve will display the number of earthquakes that occurred as a function of time.

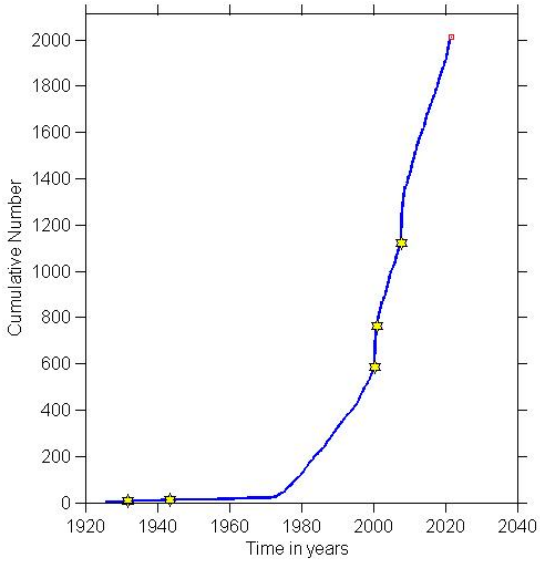
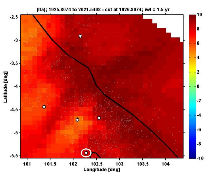


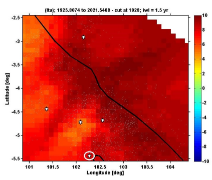
Figure 3. Comulative Number Curve

In Figure 3 the number of earthquakes during 1925-2021 is a function of time which is used on the LTA curve. In the 1925-2021 curve before the 2000 earthquake, 600 earthquake events occurred. After the earthquake in 2000, there were 2 earthquakes in 2001 and in 2007 the increase in the incidence of earthquake events was very significant so that the total number of earthquakes became as many as 2297 earthquake events that occurred in Bengkulu Province on land and sea.

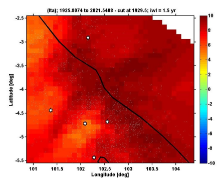
Figure 4 depicts the regional distribution of z-value in the region of the Bengkulu Province prior to the 1934 earthquake, which had a magnitude of 7.0 SR.



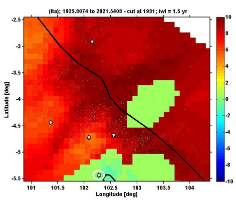
(a)



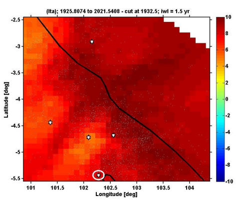
(b)



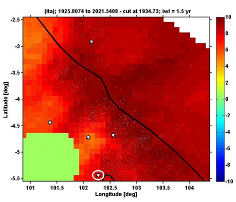
(c)



(d)



(e)



(f)

Figure 4. The z-value's spatial distribution prior to the 1934 earthquake event (7.0 SR) with iwl = 1.5 years: (a) cut at 1926.5 (b) cut at 1928 (c) cut at 1929.5 (d) cut at 1931 (e) cut at 1932.5 (f) cut at 1934.73

The z-value distribution prior to the 1934 earthquake, which had a magnitude of 7.0 on the Richter Scale, is seen in Figure 4. The distribution of z-value is presented in multiple time slices every 1.5 years starting from the cut at 1926.5 using Tw=iwl 1.5 years. Seismic activity is denoted by a positive z-value (seismic quiescence), which is shown in red, and a negative z-value (seismic activity), which is highlighted in green to blue. Based on Figure 4, a seismic quiescence phenomena existed prior to the 1934 earthquake occurrence.

Figure 5 depicts the regional distribution of z-value in the region of the Bengkulu Province prior to the 1943 earthquake, which had a magnitude of 7.0 SR

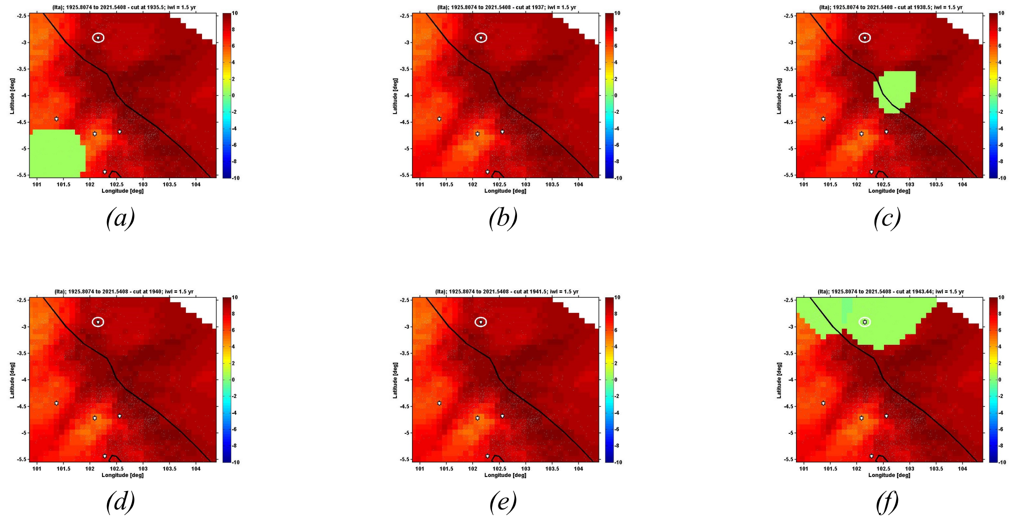


Figure 5. The z-value's spatial distribution prior to the 1943 earthquake event (7.0 SR) with iwl 1.5 years (a) cut at 1935.5 (b) cut at 1937 (c) cut at 1938.5 (d) cut at 1940 (e) cut at 1941.5 (f) cut at 1943.44

Figure 5 depicts the z-value distribution before the 1943 Bengkulu Province earthquake, which had a magnitude of 7.0 on the Richter Scale. The spatial distribution of z-values is shown in time slices every 1.5 years starting from the cut at 1935.5 to 1943 with Tw=Iwl 1.5 years. While a negative z-value denotes an increase in seismic activity, a positive z-value denotes a reduction in seismic activity (seismic quiescence), which is represented in red. Based on Figure 4, a seismic quiescence phenomena existed prior to the 1943 earthquake occurrence.

Figure 6 depicts the regional distribution of z-value in the region of the Bengkulu Province prior to the 2000 earthquake, which had a magnitude of 7.0 SR.

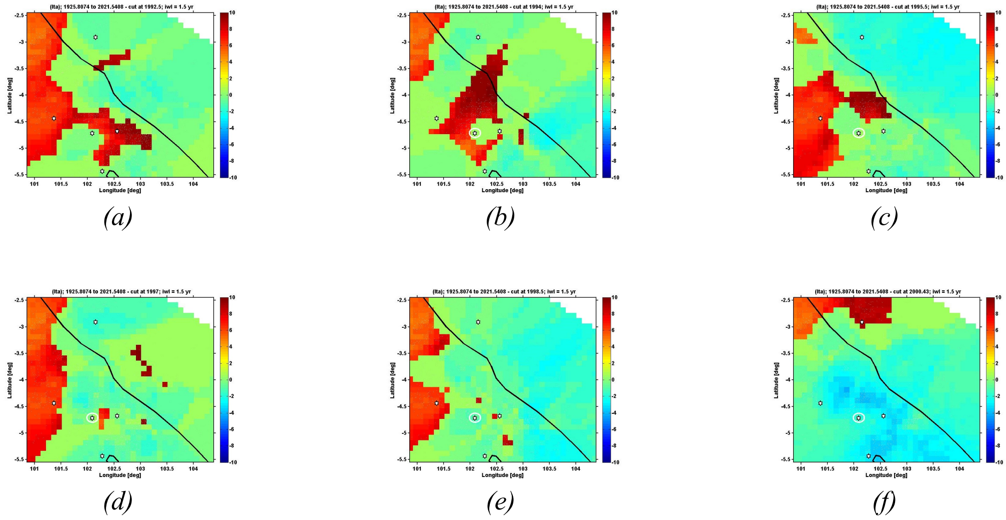


Figure 6. The z-value's spatial distribution prior to the 2000 earthquake event (7.0 on the Richter scale) with an iwl of 1.5 years (a) cut at 1992.5 (b) cut at 1994 (c) cut at 1995.5 (d) cut at 1997 (e) cut at 1998.5 (f) cut at 2000.43

Figure 6 depicts the distribution of z-values before to the occurrence of the Bengkulu Province earthquake in 2000, which had a magnitude of 7.0 on the Richter Scale. The spatial distribution of z-values is presented in several time slices every 1.5 years starting from the cut at 1992.5 to 2000 with Tw=Iwl 1.5 years. While a negative z-value denotes an increase in seismic activity, a positive z-value denotes a reduction in seismic activity (seismic quiescence), which is shown by green to blue colors. According to Figure 6, 2000.43 there was a seismic quiescence phenomena before to the 2000 earthquake occurrence.

Figure 7 depicts the regional distribution of z-value in the region of the Bengkulu Province prior to the 2001 earthquake, which had a magnitude of 7.0 SR.

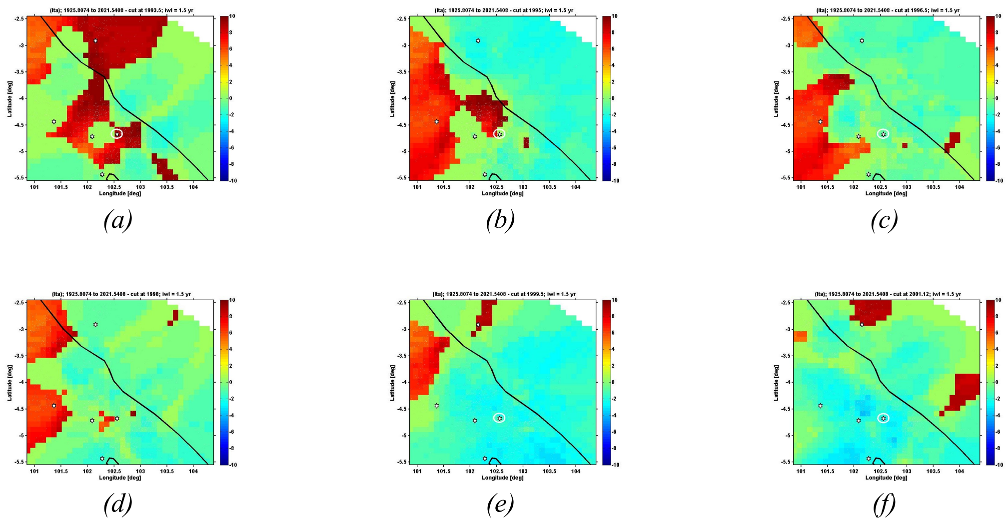
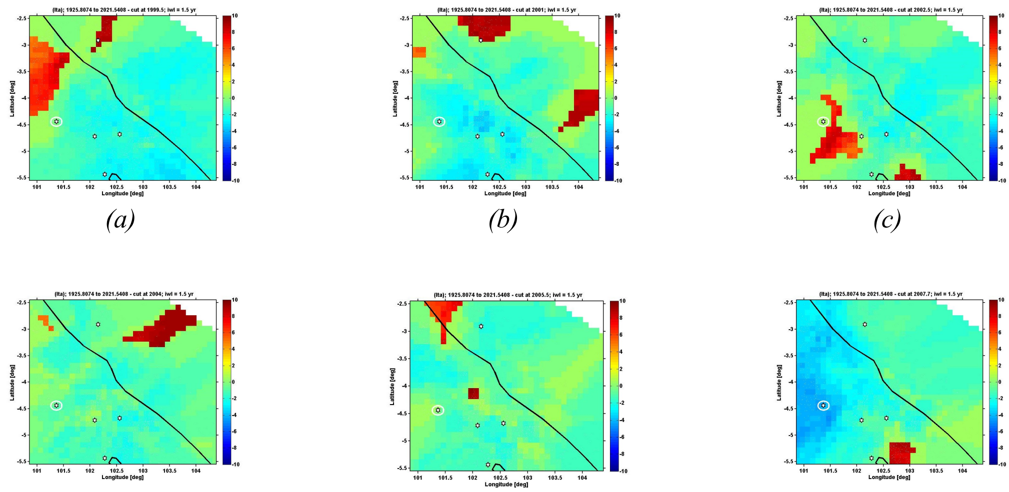


Figure 7. The spatial distribution of z-values before the 2001 earthquake event (7.0 on the Richter scale) with an iwl of 1.5 years (a) cut at 1993.5 (b) cut at 1995 (c) cut at 1996.5 (d) cut at 1998 (e) cut at 1999.5 (f) cut at 2001.12.

Before the earthquake in 2001 with a magnitude of 7.0 SR had somewhat different seismic activity (seismic quiescence), figure 7 shows the regional distribution of z-values. This distinction can be seen in the decline in seismic activity, which was limited up to the 1998 cut and did not start with a seismic quiescence phenomena at the 1999.5 cut before the earthquake. Because of the big 7.0 SR earthquake that occurred in 2000 and the proximity of the two epicenters in the third zone earthquake event, the lack of a seismic quiescence phenomena is conceivable. Based on the earthquake events in 2000 and 2001, it can be observed that the seismic quiescence anomaly will combine into a single anomaly in two subsequent earthquake events [12].

Figure 8 depicts the regional distribution of z-value in the region of the Bengkulu Province prior to the 2007 earthquake, which had a magnitude of 7.7 SR.



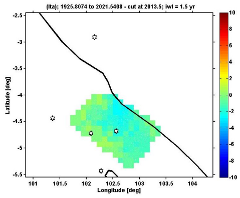
(a) *(b)* *(c)*

(d) *(e)* *(f)*

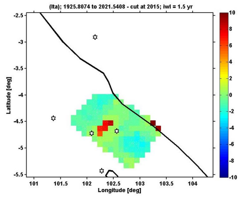
Figure 8. The spatial distribution of z-value before the 2007 earthquake event (7.7 SR) with an iwl of 1.5 years (a) cut at 1999.5 (b) cut at 2001 (c) cut at 2002.5 (d) cut at 2004 (e) cut at 2005.5 (f) cut at 2007.7.

Figure 8 depicts the z-value distribution prior to the 7.7-magnitude earthquake that struck Bengkulu Province in 2007. The spatial distribution of z-values is shown in time slices every 1.5 years starting from the cut at 2002,5 to 2007 with Tw=Iwl 1.5 years. Seismic activity that is decreasing (seismic quiescence), as indicated by a positive z-value, is highlighted in red, while seismic activity that is increasing (seismic quiescence), as indicated by a negative z-value, is highlighted in blue. Figure 8 shows that it was characterized by a seismic quiescence phenomena before to the 2007 earthquake.

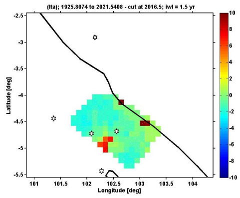
Figure 9 shows the distribution of z-value in the seismically active Bengkulu Province, which has coordinates of -5.6° to -4° South Latitude and 101.6° to 103.4° East Longitude.



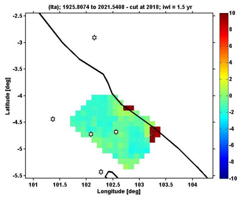
(a)



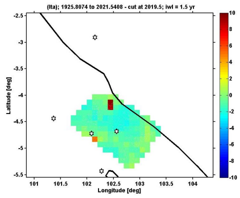
(b)



(c)



(d)



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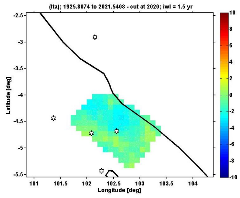

(f)

Figure 9. The spatial distribution of z-value with iwl = 1.5 years in the high activity zone (a) cut at 2013.5 (b) cut at 2015 (c) cut at 2016.5 (d) cut at 2018 (e) cut at 2019.5 (f) cut at 2020

Figure 9 displays the z-value distribution in seismically active regions for latitude and longitude values of -5.6° to -4° South and 101.6° to 103.4° East, respectively. Multiple time slices of the z-value portrayal are shown, starting at 2013,5 through 2020 with Tw=Iwl 1.5 years Seismic quiescence is indicated by a positive z-value represented by red, whereas a rise in seismic activity is indicated by a negative z-value marked by green to blue hues. According to Figure 9, the seismic activity (seismic quiescence) is decreasing from the cut at 2013.5 to 2016.5, and it is significantly increasing from the cut at 2018 to 2020.

Figure 10 depicts an area with little seismic activity, indicating that the zone chosen is one where earthquakes are infrequent. The chosen location is located between -4.2° and -2.5° South Latitude and 102.6° and 104.5° East Longitude. Spatial distribution of Z-values.

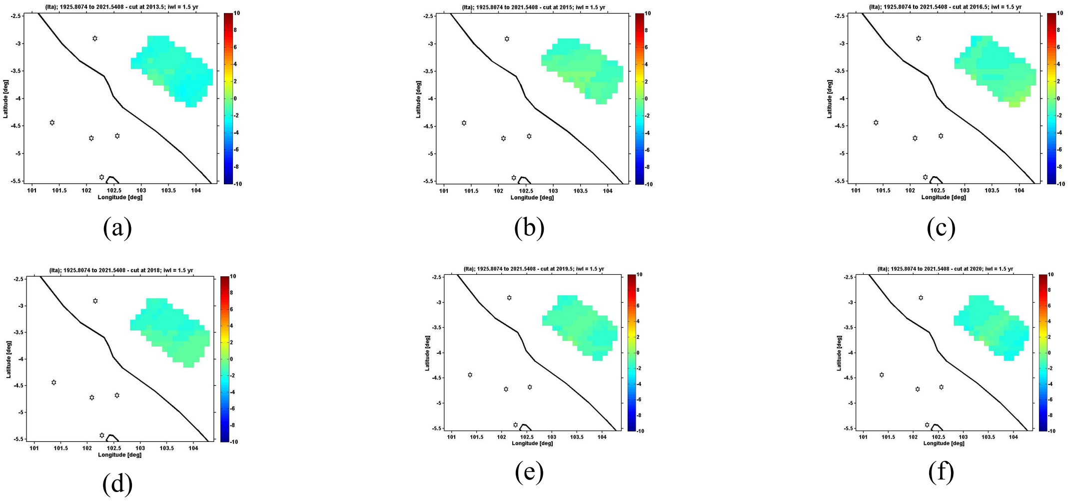

Figure 10. Bengkulu Province's spatial distribution of z-values with an iwl of 1.5 (a) cut at 2013.5 (b) cut at 2015 (c) cut at 2016.5 (d) cut at 2018 (e) cut at 2019.5 (f) cut at 2020

Figure 10 depicts an overview of the area's seventh zone. This figure depicts the Z-value distribution in a seismically active location with coordinates -4.2° to -2.5° South Latitude and 102.6° to 103.4° East Longitude. The Z-value representation is shown in numerous time slices from 2013.5 to 2020, with Tw=Iwl 1.5 years. A positive Z-value in red denotes a decrease in seismic activity (seismic quiescence), whereas a negative Z-value in green to blue denotes an increase in seismic activity. According to the graphic, there was a less substantial decline in seismic activity from the 2015 cut to the 2019 cut,5 with light blue to yellowish hues, and an increase in seismic activity with more green to blue colors in the 2020 cut.

Figure 11 depicts the eighth zone, namely the regional distribution of Z-values at the start of 2021 in the Bengkulu Province area.

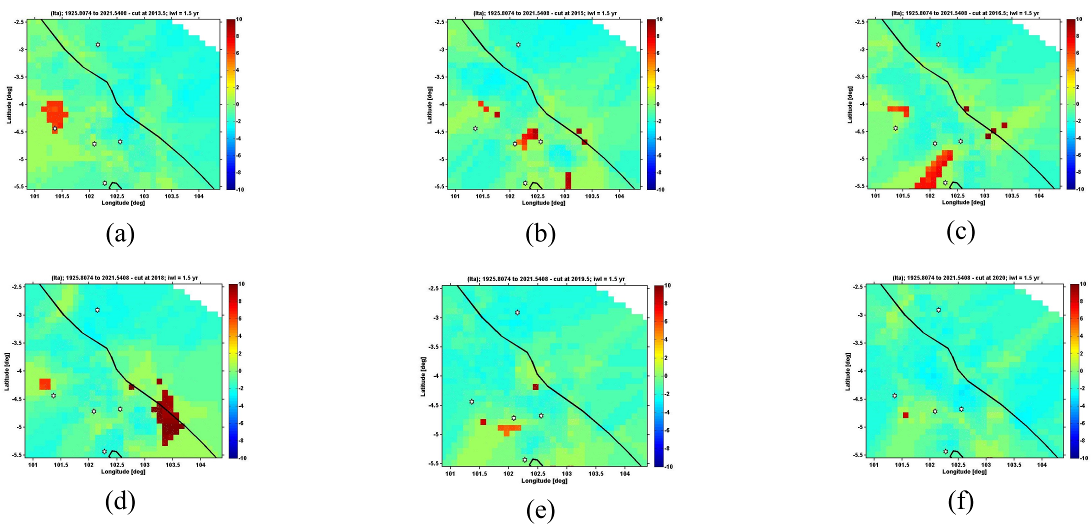

Figure 11. Bengkulu Province's spatial distribution of z-values with an iwl of 1.5 (a) cut at 2013.5 (b) cut at 2015 (c) cut at 2016.5 (d) cut at 2018 (e) cut at 2019.5 (f) cut at 2020

Figure 11 depicts the Bengkulu Province's z-value distribution at the beginning of 2021. The purpose of this is to monitor the seismic activity in the Bengkulu Province. Multiple time slices of the z-value portrayal are shown, starting at 2013,5 through 2020 with Tw=Iwl 1.5 years. A negative z-value shown by green to blue suggests an increase in seismic activity, whereas a positive z-value indicated by red hue indicates a reduction in seismic activity (seismic quiescence). A positive z-value in red on Figure 11 indicating a decrease in seismic activity (seismic quiescence) from cut at 2013, 5 to cut at 2018 is shown. Furthermore, at cut at 2019.5 and cut at 2020 there was an increase in seismic activity which was indicated by the increasing number of areas with a negative z-value with an increasing number of blue colors.

The energy in the seismically active region per unit of time, or the change in the number of earthquakes, is the seismic rate change. Based on the results of research that has been carried out, it can be seen that there is a change in the seismic rate seen in several years before and after the major earthquakes in 1934, 1943, 2000, 2001 and 2007. Before the main shock, there was silence in the form of a decrease in seismic activity (seismic quiescence). This is indicated by a negative z-value in the region. The stress and strain on the rock that have not yet reached the rock's bearing capability are described by this phenomena. The magnitude of the earthquake provides insight into the quantity of energy released. Seismic activity in the region increased following the earthquake. This is the case since the z-value is negative and there has been significant energy expenditure. However, if two nearby earthquake occurrences combine the seismic quiescence anomaly into a single anomaly, the anomaly will be the lack of a drop in seismic activity brought on by impending large earthquake events.

The spatial distribution of z-values in the area reveals that the seismic rates in the Bengkulu Province has changed over time. The spatial distribution of z-value can be observed when, before to a significant earthquake, there was a drop in seismic activity that was indicated by a positive z-value surrounding the mainshock. And when an earthquake approaches, seismic activity rises along with a z-value's gradual decline to a negative value until the major earthquake happens. A negative z-value indicates that after the primary earthquake, there will be an increase in seismic activity in the region. The degree of the rise in seismic activity depends on the quantity of energy released.

4. Conclusion

Based on research that has been carried out, Bengkulu Province has high seismic activity. This is shown by the seismicity distribution map for the period 1925-2021. High seismic activity is indicated by frequent earthquakes in the Bengkulu Province. the results of the z-value distribution in eight research zones in the Bengkulu Province. This study is divided into eight zones, with five of them being research zones based on the phenomena of a drop in seismic activity (seismic quiescence) before the occurrence of a big earthquake event, which occurred anomalously in 2001. The sixth and seventh zones are slices of areas that experience high seismic activity and areas that rarely occur. seismic activity (seismic gap). The eighth zone in 2020 and at the time junction from 2013 to 2020 there was an increase in seismic activity. In other areas of the time slice, there is a less abrupt decline in seismic activity, which causes energy to store up. However, this rise in seismic activity has not been accompanied by a large earthquake throughout this time. According to data obtained from five earthquake events, namely 1934, 1943, 2000, 2001 and 2007 seismic changes occurred before the main shock occurred in the form of a decrease in seismic activity. However, there were several anomalies in 2001, namely the absence of a seismic quiescence phenomenon prior to the main shock due to two significant earthquakes in the near future.

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